INFORMATION MATERIAL RELATED TO THE CONSIDERATION OF THE DRAFT INTERNATIONAL CONVENTION FOR THE PREVENTION OF POLLUTION FROM SHIPS, 1973 AND ITS ANNEXES

Submitted by the Government of the United States of America

Attached hereto* for information is a "Report of the Relative Harmful Effects of Crude Oil and Selected Petroleum Refined Products on Certain Commercially Valuable Finfish and Other Marine Organisms (Relative Harm of Selected Oils)" submitted by the Government of the United States of America.

* Due to the limited number of copies available only one copy per delegation (in English) will be distributed during the Conference.
A REPORT OF THE RELATIVE HARMFUL EFFECTS
OF CRUDE OIL AND SELECTED PETROLEUM
REFINED PRODUCTS ON CERTAIN
COMMERCIALY VALUABLE
FINFISH AND OTHER
MARINE ORGANISMS
RELATIVE HARM OF SELECTED OILS

Prepared by: Robert P. Hannah, Marine Biologist, National
Aeronautics and Space Administration,
Mississippi Test Center/General Electric Company

Henry D. Van Cleave, Chief, Oil Branch,
Division of Oil and Hazardous Materials,
U.S. Environmental Protection Agency,
Washington, D.C.
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1.0 **Background and Summary**

At the 13th session of the Marine Pollution Subcommittee of the Maritime Safety Committee (IMCO) the United States submitted evidence to show a need to control discharges of all oils into the marine environment. During the course of discussions a basic question was raised with respect to the control of light oil discharges when harm from such discharges have not been thoroughly investigated. It was recognized that much of the data presented was the result of literature surveys which were general in nature. Few studies have been made with light oils which documented specific harm in the open ocean.

In an effort to pursue further the necessity to demonstrate harm to marine resources from light oil discharges from ships, the United States, through the U.S. Environmental Protection Agency, undertook to conduct laboratory investigations on certain commercially valuable finfish using selected refined petroleum products. This investigation commenced in July 1972 and is continuing.

This report is prepared to inform attending nations of the results of the studies to date and to relate such data to a ranking system based on demonstrated harm. The investigations over the past year focused on lethal and sublethal effects testing through bioassay techniques of selected oils on certain commercially valuable species of fish. The literature was reviewed only to point out data related to a specific species of test organisms or specific effects not covered by the study, such as biodegradation, effects on human health, chronic effects and persistence. Figure 3 is a graphic presentation of the various conclusions drawn in this report.
The report is summarized here to highlight major conclusions; however, those interested in more detailed discussion may wish to read the full report.

Major Conclusions

1) Acute Toxicity. Acute toxicity of oils on menhaden, mullet and catfish show that these fish are less tolerant to refined products than to crude oil. This is most apparent on early life forms and juvenile marine fish. Eggs and larval forms of mullet are found at the water surface near the 200 fathom depth contour. Menhaden spawn offshore and eggs are found at the water surface near the 50 fathom depth contour. Therefore, light oil discharges in the open ocean could have more toxic effects on the early life forms of menhaden and mullet than crude oil.

2) The median tolerance limit of menhaden and mullet to fuel oil #2 was 4 mg/l for 96 hours of exposure. (Median tolerance limit, TLM, is the concentration that kills 50 percent of the test organisms within a specified time. It should not be inferred that a TLM value is a safe value.)

3) As a result of laboratory bioassay tests it was determined that fuel oil #2 was more toxic than crude oil to mullet and menhaden.

4) Coating and Smothering. Coating and smothering effects are pronounced with heavy oils such as fuel oil #6.

5) Chronic Effects. There is evidence that sublethal concentrations of oil in the marine environment have an adverse effect on the physiology and behavior of marine organisms.

6) Persistence. The slow rate of recolonization of areas affected by oil pollution is evidence of the persistence of oil components.
7) **Degradation.** Biological breakdown of oil in the marine environment is a selective action. The rate of utilization, which might cause decrease of the dissolved oxygen, is more dependent upon temperature and available nutrients than substrate.

8) **Bioaccumulation.** Bioaccumulation of any fraction of crude oils and petroleum refinery products present a potential hazard as follows: (a) commercially important marine species could become tainted and rejected as a food source; and (b) as an oil pollutant pathway in which oil undergoes biological-magnification and thus becomes an increased hazard to higher trophic levels.

9) **Carcinogenicity.** Higher concentrations of the carcinogenic hydrocarbon 3,4-benzpyrene are found in petroleum refinery products than in crude oil.

10) **Amenities.** The main effect under this category was coating of recreational beaches.

11) **Human Health.** Long term effects on human health is not well understood.
2.0 Introduction

Pollution of the marine environment by oil and petroleum refinery products is a problem of growing concern to the world community. The increasing demands of the industrial world for crude oil and petroleum refinery products can be supplied only by increased production from offshore wells and increased transportation of oil from production areas to the world markets. Without increased safeguards to prevent spills and to control discharges, pollution of marine environment by oil can be expected to increase.

Economic decisions concerning the expenditures for additional safeguards must be weighed against the consequences of increased oil pollution. Although many reports have been published on the adverse effects of oil to the marine environment, development to date of the quantitative aspects for the biological and ecological impact of oil has been rudimentary. However, enough information is presented to support certain important assumptions concerning the environmental impact of a given oil relative to another oil. It is the purpose of this study to propose use of environmental profiles showing the relative hazards of oil, based on reports in the literature and information from current research projects.

In general, there are two study approaches which have been used to evaluate the effects of oil; they are the in situ studies, usually performed following a major spill and laboratory bioassay studies. The spill disaster studies usually encompass an assessment of the immediate impact as it relates to the death of a wide variety of organisms and a follow-up study on the reestablishment of organisms. While lacking quantitative aspects, field studies indicate the wide detrimental biological consequences
of oil pollution. The laboratory approach offers quantitative information on the adverse effects of oil on relatively few organisms. Because of different laboratory approaches used to evaluate oil, comparative data of the acute and chronic effects of oil are rare.

3.0 Procedure

The lack of comparative data on all oils limited development of the relative hazardous profile of oil to the following: crude oil, fuel oil #6, fuel #2, jet fuel, and gasoline. The profile addresses the general marine environment rather than the ecological zone or trophic approach such as estuary and open ocean or plankton and nekton.

The hazard profile is a relative rating of the above oils as related to: 1) acute hazard, 2) chronic hazard, 3) persistence, 4) degradation, 5) bioaccumulation, 6) carcinogenicity, 7) amenities, and 8) human health. A number ranking was assigned to rank the crude oil and refinery products when quantitative data were available. A rating of ++ was assigned to an oil when quantitative data were not available, but a known detrimental effect was evidenced. A rating of + was assigned to an oil if there was some evidence of harmful effects, but the degree of harm had not been established. A rating of * indicates no evidence to support whether the oil is harmful or not. (See Figure 3).

4.0 Acute Hazard

4.1 Acute toxicity

Relative acute toxicity data allows a quantitative approach to the comparison of the lethal effects of oil on marine organisms. Some reports have been published with quantitative aspects of the toxicity of oil to
phytoplankton, zooplankton, shellfish, and fish. Fish were used as the principal indicator organism to derive acute toxicity hazards profile ranking for crude oil and petroleum refinery products. Fish were selected because of their commercial importance and because of the volume of data available. Supportive evidence for the ranking was obtained from data on effects of oil on shellfish and to a lesser degree for data on effects of oil on plankton.

One important step in the evaluation of the effects of oil is to determine the relative acute toxicity of crude oil and refinery products to selected fish species. The toxic effects of oil on menhaden, mullet and catfish are used as an example of the impact of oil on the coastal and open ocean environment. Therefore, such relative toxic effects are shown on not only commercially valuable fish species (menhaden and mullet), but also catfish, which has no important commercial value, but is found in significant biomass in estuarine areas to be important to an estuarine ecosystem.

Before employing bioassay data to evaluate the effects of oil on the environment, it is essential to equate the actual concentration of oil in the water column with the observed effects of that oil. The median tolerance limit (TLm) values based on total oil concentration may grossly underestimate toxicity of oil to marine life, for it is the concentration of oil throughout the water column (dissolved oil) that largely governs the toxicity of the mixture. Increased energy, such as mixing, blending or stirring, at the water-oil interface will increase the concentration of the dissolved oil or dispersed oil in the water column. Thus, the amount of energy applied in mixing for the preparation of test solution for
biowaste, for disposal of oil, or the sea state in a spill area will largely govern the amount of any one form of oil dissolved in the water column and therefore, the toxicity of that oil in the water column.

(Figure 1)

Regardless of the amount of energy applied to the oil and water interface to produce mixing, the level of concentration of the oil in the water column is dynamic. The changes in the concentration of oil in the water column can be attributed to evaporation, dissolution, bacterial degradation, absorption and other processes. These physical-chemical-biological processes will be determinative in promoting exposure of organisms to oil pollution.

Oil concentration in the water column varies with time and spatial variations of oil in water have been noted. The most important aspect of the vertical gradient of the oil concentrations occurs at the oil-water interface, for it is here that the oil concentration may be the greatest. However, in the long run the concentration of oil may be greatest at the sediment-water interface.

Unfortunately, the dynamics of oil in water makes interpretation of both in situ and laboratory observation difficult. One step in resolving these problems is to define the environmental conditions in terms of the concentration of oil as it relates to the state of organism activity during various periods of time in a life cycle.

The mullet fishery in the northeastern Gulf of Mexico depends primarily on the black mullet (Mugil cephalus) and accounts for the largest portion of Florida's west coast finfish catch. Production peaks are in the fall. Mullet are caught by gill nets and usually sold fresh or dry salted.
The mullet is a semi-catadromous species which spawn in the Gulf of Mexico; the young migrate to their estuarine nursery area, where they grow to sub-adults; they then return to the ocean where their life cycle is completed. During spawning, the mullet release eggs and sperm into the open Gulf waters. The eggs are buoyant and become a part of the near surface zooplankton. After development to the free swimming larval form, the mullet migrate to the coastal and estuarine area. Both the eggs and larval forms of mullet are found in the Gulf as far from the coast as the 100 and 200 fathom lines (in the Gulf of Mexico this is usually in excess of 50 miles from shore). (See Figure 4)

The tolerance limits of the larval mullet have been estimated for various petroleum refinery products and crude oil (Figure 2). Studies estimated the tolerance of the mullet by static bioassay producers and based the TLM values of the concentration of oil in the water column. However, the levels of concentration of oil in the test solution were dynamic, therefore, TLM values were based on the highest concentration of oil in solution as determined by chemical analysis. Table 1 indicates that the tolerance of mullet varied greatly with the material tested. Mullet were least tolerant to fuel oil #2 (TLM 4 ppm) and most tolerant to crude oil (TLM <400 ppm). The refinery products tested in order of decreasing toxicity were: fuel oil #2, fuel oil #6, jet fuel, leaded gasoline, and unleaded gasoline.

Menhaden (Brevoortia patronus) is the leading fishery product in the U.S. in terms of pounds landed. In the northeastern Gulf, the menhaden fishery is concentrated between Louisiana and Mobile Bay. The annual catch is about 400 million pounds (Taylor, J.L., et al., 1973) in this area.
Menhaden are caught by the purse seine method and are used primarily for fish meal, oil, and fish solubles.

Menhaden are a semi-catadromous species that spawn in the open waters of the Gulf of Mexico from October through March. The buoyant eggs of the menhaden are found one meter beneath the surface at the 50 fathom line (a greater distance than 50 miles from the shore) from Cape San Bas, Florida to Texas. The greatest concentrations are found off the Mississippi Delta. The eggs of the Atlantic menhaden are found in large concentrations in the spawning area off the Carolina coast near Cape Fear. The young menhaden migrate to their estuarine nursery area, where they grow to adults, then return to the open water where their life cycle is completed.

The tolerance of menhaden to fuel oil #2 was estimated to be 4 mg/l for 96 hours of exposure. This TLm value is very close to that of the mullet. The tolerance of menhaden to jet fuel was estimated to be 80 mg/l for 96 hours of exposure.

The juvenile sea catfish (*Gaieichthys felis*) is not considered an important commercial species, however, it is found in significant biomass in estuarine areas to be important to an estuarine ecosystem. The tolerance of the catfish to fuel oil #2 and to fuel oil #6 was 17 and 24 mg/l, respectively, for 96 hours of exposure. These values are comparable to those established for mullet for the same refinery products.
**TABLE 1**

TL\textsubscript{m} Values of the mullet, *Mugil Cephalus*, exposed to petroleum refinery products and crude oil for 96 hours. The TL\textsubscript{m} values are based on the highest concentration of oil in the water column during the test.

<table>
<thead>
<tr>
<th>Material</th>
<th>TL\textsubscript{m} 96 - mg/l</th>
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<tbody>
<tr>
<td>Fuel Oil No. 2</td>
<td>4</td>
</tr>
<tr>
<td>Fuel Oil No. 6</td>
<td>28</td>
</tr>
<tr>
<td>Jet Fuel</td>
<td>100</td>
</tr>
<tr>
<td>Leaded Gasoline</td>
<td>260</td>
</tr>
<tr>
<td>Crude Oil</td>
<td>( \leq 400 )</td>
</tr>
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</table>
Studies by Mironov (1968, p. 336) on the development of fertilized eggs of the plaice (*Rhombus macoticus*) showed extreme sensitivity of the eggs to the influence of oil products present in seawater. He noted that injury to the eggs occurred at concentrations of $10^{-4}$ to $10^{-5}$ ml/1 (0.1 to 0.01 ppm). In these concentrations of oil products, 40 to 100 percent of the hatched pre-larvae showed some signs of degeneration during development and perished. Mironov (1969a) also demonstrated that 1 ppm crude oil was toxic to the eggs of anchovy, scorpion fish and sea parrots from the Black sea.

Effects of Crude Oil Suspension on the Eggs and Larvae of *Rhombus Maeoticus*

<table>
<thead>
<tr>
<th>PPM Oil</th>
<th>Eggs</th>
<th>Larvae</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time</td>
<td>% Mortality</td>
</tr>
<tr>
<td>100</td>
<td>48 hr</td>
<td>100</td>
</tr>
<tr>
<td>10</td>
<td>72 hr</td>
<td>100</td>
</tr>
<tr>
<td>0.1</td>
<td>4 d</td>
<td>11-45</td>
</tr>
<tr>
<td>0.01</td>
<td>4 d</td>
<td>(delayed)</td>
</tr>
</tbody>
</table>

Pacific herring spawn during the spring and their eggs attach to material in the intertidal zone where they are exposed to any floating oil and oil dispersions obtained by mechanical or chemical means. Kuhnhold (1970, p. 8-10) working with the Atlantic herring and other fishes and several types of crude oil found that toxic components are dissolved from oil films injuring larvae and younger stages of floating eggs. He noted that even if the concentration of dissolved compounds
are sublethal to eggs, the embryos can be injured and the hatched larvae are even less resistant. The study emphasized the variability in results between tests using the various crude oils and the difference in toxicity of various stages of the life cycle of herring, as well as between similar life stages of other species of fish. For example, herring larvae were less resistant and plaice larvae were more resistant than cod larvae of the same age.

Several studies (James, 1926; Kuhnhold, 1969, 1970; Chipman and Galtsoff, 1949; Mironov, 1967, 1968, 1969a, b, c) have demonstrated that various oils including crude oil are toxic to several species of marine fish eggs and larvae. The toxic concentrations ranged from 1 ppm to $2 \times 10^4$ ppm.

Shellfish

The shrimp fishery in the eastern Gulf of Mexico represents about one-quarter of the volume (31 million pounds) and one-fifth of the value ($23 million) of the entire Gulf's shrimp harvest (Taylor, J.L., et al., 1973). The three most important species taken are the brown shrimp, *Penaeus aztecs*; white shrimp, *P. setiferus*; and pink shrimp, *P. duorarum*. Royal red shrimp and rock shrimp are also utilized but have not reached their full potential as fisheries. Shrimp fishing vessels range up to 50 gross tons and travel far out into the open ocean. Larger vessels employ double trawls and are capable of making extended trips, up to 50 days. The smaller vessels usually employ a single trawl and fish close to shore with an average trip of 2 to 4 days (Taylor, J.L., et al., 1973). The most important species of shrimp are concentrated in the estuaries and near shore in the coastal waters. However, the Royal red is found in open
waters beyond the 50 fathom line (usually greater than 50 miles from the coast).

The tolerance of shrimp to crude oil was estimated to be 15 mg/l for 96 hours of exposure (personal communication with Mississippi State University). Some evidence indicates that crude oil may interfere with reproduction of shrimp.

Fuel oil #2 was toxic to grass shrimp at 135 mg/l total oil concentration which equates to be a TLm for 96 hours of less than 5 mg/l in the water column. Leaded gasoline produced mortalities after the shrimp were exposed for 24 hours. These shrimp were exposed to 2000 mg/l of total gasoline which equates to be 320 mg/l in the water column. (EPA/NASA)

The effect of Venezuelan crude oil on lobster larvae has been reported recently by Wells (1972). This author achieved emulsification of oil with sea water by stirring and the use of an ultrasonic probe. Aliquots of the emulsion were removed from below the surface layer. Because of the tendency of the emulsion to separate, Wells concluded that the concentrations of oil in sea water are possibly overstated. His test organisms were Homarus americanus larvae. These larvae were exposed to sublethal concentrations of Venezuelan crude oil continuously for periods of up to 10 days at 20-21°C. Relatively few larvae were exposed at each concentration level (4-5 larvae) and some mortality occurred in the control organisms. A concentration of 100 ppm was lethal at all stages of development in 24 hours. Susceptibility of the different stages of development varied at a concentration of 10 ppm for 96 hours. Early stages of development were more sensitive than later stages. Survival was "high" at 1 and 0.1 ppm. Half the test species died within 96 hours at
concentrations ranging between 30 and 2 ppm. Mortality generally occurred when ecdysis was taking place. "Marked changes in colour and behaviour" were noted among larvae exposed to 100 and 10 ppm of oil. In longer term exposures, up to 30 days at 20-21°C with ten larvae at each of four concentration levels from 10 ppm and below and 40 control larvae untreated, larvae in 1 and 0.1 ppm survived and developed normally like the controls. At higher concentration levels, the evidence suggests that development was slowed down, became abnormal, or was suspended altogether. The mean survival period at 10 ppm was 9 days compared with 23-30 days at lower concentration.

Mironov (1969b) tested crude oils on several copepods and a cladoceran, finding that 1 ppm killed all forms within less than a day. Acartia and Calanus were reported (Mironov, 1968, p. 336) to succumb to 0.01 ppm oil in sea water in 72 to 96 hours. Although surviving longer than copepods, larvae of crab and shrimp also die at 1 ppm (Mironov, 1969c). Two of the copepods tested, Acartia clausi and Paracalanus parvus, occur in Alaskan waters.

**Shellfish, Excluding Shrimp**

Among shellfish, excluding shrimp, oysters are the most valuable catch. Blue crabs and oysters are found virtually throughout the northeastern Gulf of Mexico coastal area, while other shellfish (sunray-venus clams, hard clams, stone crabs, bay scallops, turtles, and sponges) are taken on a more localized basis.

Resident species complete their life cycle in estuaries and are dependent on this zone most of the time. Oysters and blue crabs are classed as resident species although blue crabs may, for a short time,
venture into the shallow coastal waters. Both species contribute significantly to the commercial fishery, and the blue crab is sought by recreational fisherman.

Acute toxicity for mature oysters exposed to blended crude oil was estimated to be greater than 400 ppm (Mississippi State University). The tolerance of crab larvae to crude oil was estimated to be 1 ppm (Mironov). The Anacortes Report (Watson, 1971) on effects of a diesel fuel spill concluded in part that those life forms killed were chitons, large limpets, large and small pelecypods, and large gastropods. Apparently, the molluscan fauna is the most susceptible to the toxic effects of diesel fuel. This was also noted by Sanders and Blumer (personal communication).

4.2 Coating and Smothering

Animal locomotive ability implies a need for greater supplies of energy than is the case for plants, for this follows the catabolic mode of metabolism and the need for a greater supply of oxygen than is required by plants. Most animals thus have specialized organs of respiration. In the case of small aquatic organisms many effect respiratory exchange to a greater or lesser degree through the body wall. Most of them rely to some extent on this respiratory mechanism. With the higher animal forms gills of some kind are important for respiration. These structures are invariably delicate and are protected by some scaley or shell structure relying for their effectiveness or unimpeded contact with a constant flow of oxygenated water. A few fish (the lung fish or Dipnoi) and the aquatic mammals (Cetaceans, seals, etc.) breathe air either through the mouth (Dipnoi) or external nares (Cetaceans and seals). A serious consequence would be for oil to coat small aquatic organisms, the gills of gill
breathing forms or to choke or plug the respiratory orifices in the case of gill or air breathing animals. However, this kind of phenomena could result only from the sinking of thick oil slicks when benthic fauna would be affected or from thick oil slicks being washed ashore thus affecting littoral communities. Apparently there have been no reports of fish being polluted to this extent although there have been reports of damage of fish gills. There have been reports of the oiling of cetaceans, seals, and some fur bearing terrestrial mammals.

All animals of the classes Aves and Mammalia have a body temperature above that of the environment in which they live. For insulation these animals are covered with feathers or fur. The feathers and fur are naturally coated with a fine film of greasy material which renders this insulating layer water repellant, but it also has the effect of making this layer oleophilic and thus easily contaminated by an oil. Impregnation with oil destroys the heat insulating properties of the feather or fur covering and provides an uninterrupted channel for heat drain. The loss of heat is less when the oil contaminated layer is in contact with air but is greatly increased when the oil impregnated area is in contact with water because of water's greater heat conducting qualities. Those body areas which become contaminated with oil from a water surface are naturally those body areas most likely to be in contact with water. Heat loss, if sufficiently great, results in death due to exposure. In an attempt to reduce the effects of the heat drain the animal must make use of additional food or body reserves. The lack of insulation usually impairs the ability of the animal to secure its normal food, thus body reserves (usually stored fats) are soon depleted, further destroying the
insulation of the body and death follows. Most of the deaths of oil-affected birds are due to this cause, according to assessments of post mortem condition of birds.

Birds and animals naturally take an interest in the condition of their feathers and fur because of their function in insulating their bodies from ambient temperature. They thus indulge in preening and grooming operations usually with the mouth and tongue, which inevitably results in any feather or fur contaminant reaching the mouth, and gut, and in the case of birds through the crop, on its way to the stomach. Post mortem examination of dead birds shows that contaminating oil does reach the crop and gut.

Most animals when confronted by a strange object behave in an instinctive manner and many, on sighting or feeling an oil slick, would avoid it. Some water birds, however, instinctively dive when they come into contact with a strange phenomenon. They surface in an apparently random pattern, and this can have the unfortunate consequence that they surface into the slick and thus become coated with oil. Some animals exhibit a curiosity-motivated interest in strange phenomena and such behavior can lure them into a situation where they become contaminated, although, normally, most fur bearing animals and many birds instinctively attempt to prevent the soiling of their fur or plumage.

Cellular membranes of phytoplankton are damaged by the penetration of hydrocarbon molecules, which leads to the extrusion of cellular contents and to the penetration of oil into the cell. The hydrocarbons reduce the transpiration, probably by blocking the stomas and the intercellular spaces. The effects of oils on respiration are variable, but
an increase of respiration is frequently observed, and may be due to an alteration of the mitochondria. This results in an uncoupling of the oxidative phosphorylation enzymes from the electron transport enzymes and the energy release is lost as heat (FAO, pt. 2, p. 6; Baker, 1971, p. 6).

Chan (1973) studied the effects of a Bunker C fuel oil spill in the San Francisco area and reported that from comparative transect and laboratory observations, it was determined that marine organisms died from being smothered by the oil, with certain species, such as acorn barnacles and limpets, suffering the highest mortality at Sausalito and on Duxbury Reef. Comparison of pre-oil and post-oil transect counts showed there was a significant reduction in marine life after the oil spill on the reef. Marine snails suffered less mortality than the sessile barnacles and other sedentary animals. The normally large population of striped shore crabs was missing from the rocky crevices. Chan concluded that smothering was by far the most important factor in the marine organism fatalities attributed to contact with Bunker C oil. The decrease in marine organisms in the transect areas was not due to storm conditions, natural predators, nor zealous collecting by man, but was attributable mainly to the contamination of these organisms by the oil.

Oysters and mussels are more susceptible to fuel oil #2 than either crude oil or Bunker C. Oysters and mussels were very resistant to a Bunker C oil spill in which many other sessile, such as barnacles and limpets, died (Chan, 1973).

4.3 Conclusion on Acute Toxicity Effects of Oil

a. The concentration of an oil within the water column largely governs the toxic effects of that oil. Increased energy in any mixing
process of oil and water increases the amount of oil in solution or dispersed in the water column.

b. The impact of an oil on any given component of a biological system is dependent upon: 1) the habitat, 2) the sensitivity of the phylum, 3) the development stage, and 4) indirect harm, such as decreased dissolved oxygen.

c. The effects of crude oil and refinery products on phytoplankton, adult crustaceans, and early development stages of both invertebrates and vertebrates are similar. These life forms are susceptible to low concentrations of crude oil and petroleum refinery products.

d. Differences in the acute effects of crude oil from that of petroleum refinery products is most apparent on late developmental and juvenile marine fish. Marine fish are less tolerant to refinery products than to crude oil.

e. Bivalves such as oysters and mussels appear to be more resistant to crude oil and heavy refinery products (fuel oil #6) than to lighter refinery products (fuel oil #2).

f. Based on the differences in the biological effects of the various oils, a ranking was assigned the various petroleum refinery products and crude oil. In general, fuel oil #2 received the most toxic rating and crude oil the least toxic rating.

g. The acute biological effects of coating and smothering by oil cannot be easily distinguished from toxicity stated above or can the data be easily quantified for comparison. However, based on studies of fuel oil #2, fuel oil #6, and crude oil spills, certain differences are apparent. In general, heavy oil, crude, and fuel oil #6 form water-in-oil mixture that adheres readily to most surfaces. Observation of glass
strips exposed to various petroleum refinery products indicates that fuel oil #6 has far greater coating ability than any of the other refinery products. Fuel oil #2 was next in coating ability of the materials tested.

5.0 Chronic Hazard

Blumer cautions that low level pollution may damage the marine ecology by masking natural chemical sex attractants, interfere with identification of migration routes and interfering with chemical food sensing and enemy repulsion. He states, "There is good reason to believe that pollution interferes with these processes in two ways: by blocking the taste receptors and by mimicking of natural stimuli..." (Blumer, 1969, p. 7; 1970, p. 6).

The locomotive ability of animals is important in connection with oil pollution. Oil fractions dissolve in water and these act as chemical stimuli. There is some evidence that certain fractions exhibit a narcotic effect, particularly on the Mollusca. Narcotic effects appear to have been confined to the sedentary or slow moving species of aquatic animals and seems likely to be associated with the later effects of toxic concentrations. This is believed to be so because in almost every case where such effects have been noted, visual observation has been relied upon, and it is most difficult, if not impossible, to observe by visual means narcotic effects in the Mollusca.

Menhaden, mullet and catfish exposed to sublethal concentrations of petroleum refinery products exhibited an impaired response to stimuli. Swimming activity decreased and fish would probe at the surface after 24 hours of exposure to refinery products. With increased time of exposure, swimming movement became erratic and, at times, loss of
equilibrium occurred (EPA/NASA).

Shrimp exposed to fuel oil #2 increased their swimming activity. Such behavior may remove the shrimp from its natural protective covering and thus increase predation pressure on a shrimp community affected by fuel oil pollution. Surviving shrimp exposed to high concentration of fuel oil lost their equilibrium and were unable to right themselves (EPA/NASA). Shrimp reproduction may be impaired by sublethal quantities of crude oil (Mississippi State University).

Rice (1973) reports that pink salmon fry are sensitive in their detection and avoidance of Prudhoe Bay crude oil. Avoidance behavior of the fry were observed at concentrations as low as 1.6 mg/l of oil. The avoidance of the salmon fry was quite apparent and suggests that there is potential for oil to change their migration behavior.

Drocksen, et al., (1973) has demonstrated that benzene, a water-soluble component of crude oil, affects the respiratory metabolism of the juvenile chenook salmon and the striped bass. Fish exposed to sublethal concentrations of the aromatic hydrocarbon benzene showed an increase in respiration rates up to 115 percent above controls for the 24 hour of exposure. Fish exposed to longer periods of time in 10 ppm of benzene exhibited a narcosis that caused a decrease in respiratory rate.

Manifestation of sublethal effects of crude oil are expressed in the physiological state and the behavior of marine fish. Small quantities of oil in the marine environment that effect the energy utilization or the migration behavior of fish will result in a decrease in production over time.

Effects of crude oil on the metabolism of two common filter feeding animals (Mytilus edulis and Modiolus demissus) were investigated by
Galfillan (1973). Results of preliminary experiments on the physiological effects of sea water extracts of crude oil on *Mytilus edulis* indicated that seven different crude oils were not acutely toxic to *Mytilus* (Gilfillan, unpublished data). One important result of these first experiments was the discovery that small amounts of oil extract can dramatically increase respiration rates. Further experiments showed that at the same time, feeding rates could be greatly reduced. These results imply that small amounts of crude oil can decrease the amount of energy available for maintenance, growth and reproduction. This paper reports on the combined effects of crude oil and salinity stress on the carbon budget of two common filter feeding mollusks, *Mytilus edulis* (the blue mussel) and *Modiolus demissus* (the marsh mussel).

Decreased limb (cirral) activity of marine larvae exposed to oil has been reported (Smith, 1968, p. 135).

Olefinic hydrocarbons not present in crude oils but present in petroleum refinery products are reported as likely to interfere with the reception of chemical messengers in the sea by marine organisms (Blumer, 1970, p. 6).

Baker (1973) reporting on the biological effects of refinery effluents states that although most undiluted refinery effluents can be shown to be toxic in the long term, they are not usually acutely so. They can cause sublethal effects such as changes in metabolic rate or behavior, and such effects over a long period of time may help to explain population changes near discharges.
5.1 **Conclusion on Chronic Hazard**

1. There is evidence that low level sublethal concentrations of oil in the marine environment have an adverse effect on the physiology and behavior of marine organisms.

2. A reasonable assumption concerning the relative sublethal effects of oil would be that chronic effects of oil to marine organisms would be directly related to the acute toxicity of oil to marine organisms. Therefore, the oil producing toxic effects at the lowest relative rate would be expected to produce sublethal effects at a similar position in a relative ranking of the chronic effect.

3. Long term low level effect of an oil would be determined in part on the oil's persistence in the environment as well as bioaccumulation and carcinogenic considerations.

4. Based on the above considerations, a relative ranking for crude oil and petroleum refinery products was determined. Had the profile been determined for a continuous effluent of an oil into the environment, the ranking would have been the same as that of the acute hazard toxicity ranking. However, the above mentioned factors were weighed to develop a chronic effect ranking applicable to spills and intermittent discharges.

6.0 **Persistence**

In oil producing areas, oil residues have often been observed on sandy beaches (ZoBell, 1962, p. 100) and in marshes and depths of water to 15.3 m. (Blumer, Sass, et al., 1970, p. 23). A portion of the fuel oil spilled into the harbor at Resolute, Northwest Territories, Canada, late in August, 1970, went ashore there. On the basis of a casual sampling on September 3, 1970, the average penetration into the beach
material was observed to be about 3 inches (7.6 cm.) (Barber, 1971). Such oil may be buried and stay intact for a considerable time, even at the higher temperatures of the California coast (ZoBell, 1962, p. 100). Ramseier (personal communication to D. R. Evans from R. O. Ramseier, 1971), discussing the behavior of oil in the Arctic, noted that practically no aging occurs to oil under ice, emulsification was negligible, and finally, the process of biodegradation is not active at these temperatures of near 0°C and below.

Blumer and Sass, et al., (1970, p. 25) reported toxic components of fuel oil #2 present in bottom sediments the year following the West Falmouth oil spill and concluded the toxic properties of the oil slowed its biodegradation. This same spill provided a unique opportunity for the study of the immediate and long-term effects of an oil spill on an area where the previously existing environmental base was well known (Blumer, et al., 1971). One effect of the oil in the bottom sediments was to reduce the cohesion of bottom sediments of tidal marshes and the estuary by killing the benthic plants and animals. The resulting erosion spread hydrocarbons to new areas where the process was repeated. Because of the stability of the hydrocarbons in marine organisms and their persistence in bottom sediments, Blumer, et al. (1971) concluded that a single oil spill could cause a chronic pollution problem in the vicinity of that spill.

Chan (1973b), reporting on the status of the Duxbury Reef one year after a Bunker C oil spill stated that the oil was disappearing from all reef surfaces and would probably be absent in another year.

The persistence of aviation gasoline in the stream bed six months
after the spill as well as the restricted rate of recolonization of macroinvertebrates, demonstrates complicated, long-term problems resulting from the interaction of petroleum products with the environment. A follow-up study three years after the spill documented complete recovery from gasoline pollution. The average diversity value of 4.00 for all stations indicated a healthy macroinvertebrate community (Bugbee and Walter, 1973).

There is a general consensus among most persons concerned with oil pollution that oil spills harm the natural environment. Disagreement arises on assessment of the extent and duration of the damage. However, the large quantities of tar now found in the world's oceans (Horn, et al., 1971; Morris, 1970; Heyerdahl, 1971) bear witness to the slow degradation of oil residues by any of these processes.

Studies made on effects of the Buzzard's Bay oil spill by Blumer, et al., (1970a & b) indicate an extensive immediate mortality, subsequent changes in population structure, and an accumulation of hydrocarbons by plants and animals. North, et. al., (1964) report massive mortality in both animals and plants following an oil spill on the coast of Baja, California. These mortalities were followed by a protected period of recovery lasting several years. On the other hand, results of post-spill studies in the Santa Barbara Channel suggest little adverse effects of oil pollution. Likewise, Smith (1970) reports little damage resulting from oil alone as a result of the Torrey Canyon spill. These and other studies (Blumer, 1971) have mainly considered changes in community structure and in the chemistry of the ecosystem. A greater understanding of the physiological effects of oil on marine organisms could help resolve these differences.
in observed effects of oil spills.

**Persistence of crude oil and petroleum refinery products.**

<table>
<thead>
<tr>
<th>Material</th>
<th>Reference</th>
<th>Persistence (years)</th>
<th>Substrate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>Grace Coolidge Creek</td>
<td>1-2</td>
<td>Stream Bed</td>
</tr>
<tr>
<td>#2 Fuel</td>
<td>West Falmouth</td>
<td>2+</td>
<td>Sediments</td>
</tr>
<tr>
<td>#2 Fuel</td>
<td>Anacortes</td>
<td>unknown</td>
<td>Sediments</td>
</tr>
<tr>
<td>#6 Fuel</td>
<td>San Francisco</td>
<td>2-3</td>
<td>Rocks</td>
</tr>
<tr>
<td>Crude</td>
<td>Santa Barbara</td>
<td>unknown</td>
<td>Sediments</td>
</tr>
</tbody>
</table>

6.1 Conclusion on Persistence

The evaluation of the persistent effects of oil on the marine environment are based on the evidence of the direct and chemical observations of the physical presence of the oil and on the effect of that oil on the recolonization of an area adversely affected by oil pollution.

1) The decrease in the concentration of oil in the water column can be attributed to evaporation, dissolution, bacteria degradation and other processes. However, more important to the marine biological considerations is that the oil is absorbed on to the sediments and particulate material. In addition, some oils coat substrates in the intertidal zone.

2) The effect of those components of the various oil that remain in the marine environment are evidenced by the slow rate of recolonization of areas adversely affected by oil pollution. Although the duration of effects of a spill is not always clear, it can be measured in terms of years.

3) Primarily, based on data present in Table 2, a relative rating
7.0 Degradation

ZoBell (1969, p. 230), discussing oxygen requirements for oil oxidation, noted that when oil oxidizers are in contact with the normal atmosphere, as at the air-water interface, the supply of oxygen is usually adequate. In areas of intense microbial activity below the water surface, particularly in bottom sediments, oxygen may be a limiting factor. This depends upon how rapidly oxygen is consumed and how rapidly it is replenished. Replenishment may be by oxygen diffusion, water turbulence, or photosynthetic activity in shallow water. Calculating average BOD (Biochemical Oxygen Demand) requirements for various crude oil fractions, he estimated it would require all of the dissolved oxygen in about 320,000 gallons of seawater for the complete oxidation of one gallon of crude oil.

The growth of microbial populations utilizing #2 fuel oil, #6 fuel oil, jet fuel, leaded and unleaded gasoline as substrate has been demonstrated (EPA/NASA). The growth of the bacteria was directly related to the amount of hydrocarbon substrate present. Leaded gasoline was observed to be a more amenable substrate than was lead free gasoline. A demand for dissolved oxygen was related to the amount of bacterial growth.

There is some evidence that microbial action on petroleum refinery products increased the concentration of the oil in the water column. These metabolic or breakdown products of the bacteria may be of a different order of toxicity than the energy source hydrocarbon. An increase in the concentration of oil in the water column was observed after 42 hours in the static bioassay experiment to determine the effects of mixing.
(Figure 1). Log phase growth of the bacteria occurred during the first 48 hours of the experiment with the maximum cell count of bacterial growth coinciding with an increased concentration of oil in the water column (EPA/NASA). An increase in the oil in the water column that was correlated with bacteria growth was observed for jet fuel, gasoline, and #6 fuel oil.

In some bioassay experiments, the death of test specimens occurred when an increase in the oil concentration in the water column was observed. This lead to the assumption that perhaps bacterial degradation products are more toxic than the original hydrocarbons.

Bacterial populations of salt water range from ten or less to a few hundred per ml, but as reported by ZoBell (1964), it is not uncommon to find millions of bacteria per ml of oil-polluted sea water. Theoretically, the microbial oxidation of hydrocarbons proceeds primarily to carbon dioxide and water. However, biological breakdown of oil in the marine environment is a selective action. Only certain components of the hydrocarbon mixture is utilized. In addition, the rate of utilization of an amiable oil substrate is dependent upon temperature and available nutrients. Available nutrients for biodegradation decrease from estuaries toward the open ocean. Most probably, nutrients are a limiting factor to the bacteria breakdown of oil in the oceans. Intermediate products of oxidation include organic acids, alcohols, aldehydes, ketones, esters, and other oxygenated compounds. These intermediate oxidation products rarely persist because they are generally more susceptible to microbial oxidation than the parent hydrocarbons. However, during their brief chemical existence they appear to be very toxic to larval mullet.
Born (1969), conducting experiments using Gambusia affinis and Mollisensia Latipinna, found that asphaltic crude oil, napthenic crude oil and motor oil had no deleterious effects on fish even after considerable periods of incubation. After subjecting these petroleum products to microbial degradation by enrichment cultures and using the aqueous phase as a test medium that there were increased mortalities suggesting that the water soluble degradation products were responsible.

Bunker fuels are quite different from crude oils. Bunker fuel consists of high molecular weight compounds from distillation residues, plus a cutting stock of lower average molecular weight, which has been added to lower the viscosity and the flash point of the residue. This cutting stock is highly aromatic consisting primarily of aromatic and alkylaromatic compounds. Bunker fuels are quite viscous and less readily biodegraded than crude oils. (Gard and Cabet 1973).

7.1 Conclusion on Degradation

1) Degradation is an important factor in the persistence of oils in the marine environment, however, the degree microbial degradation contributes to the final fate of petroleum in the environment to CO₂ and H₂O is not known.

However, biological breakdown of oil in the marine environment is a selective action. Only certain components of the hydrocarbon mixture is utilized. The rate of utilization, which might cause decrease of the dissolved oxygen, is more dependent upon temperature and available nutrients than substrate. Available nutrients, an important factor regulating the noted biodegradation of oil, are probably a limiting factor.
2) Both crude oil and refinery products are utilized by bacteria.

3) Auto-oxidation of oil by sunlight may create a demand on dissolved oxygen in an area adversely affected by oil pollution.

4) Some evidence is presented that degradation products are of a different order of toxicity from the original carbon source, perhaps more toxic.

5) Chemical degradation was given a + rating to indicate that evidence points to possible demands upon the dissolved oxygen in a system.

8.0 Bioaccumulation

Zooplankton have been observed to ingest spilled Bunker C oil particles, with no apparent effect. Members of the Operation Oil (1970) task force, studying the effects of spilled Bunker C from the tanker Arrow in Chedubucto Bay, Nova Scotia, observed that many copepods in the area had apparently ingested small oil particles and 2.4% Bunker C was found in the feces of one species. They noted that animals containing smaller oil particles voided these within 24 hours and showed no signs of distress. That they continue normal activities with no apparent harm is quite important in consideration of the marine food chain, because they can be eaten by small fishes and filter-feeder organisms while carrying the oil in the gut. These in turn may be eaten by large predatory animals and thus all conditions are present for a classic example of biological magnification of a potentially harmful or toxic compound. A similar effect could be expected if other toxic materials such as diesel fuel, solvents, or heat exchanger fluids were spilled during handling or as a result of platform damage.

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Chronic oil pollution on zooplankton may have sublethal effects. Toxic hydrocarbons may be concentrated by zooplankters (Mallet and Sordau, 1964; Mallet and Lame, 1965; both cited in Mironov, 1968) and be passed up the food chain in the same manner as are insecticides and heavy metals.

Chemical pollution of the tissues of organisms can be detected by advanced analytic methods such as are employed by Blumer, Souza, and Sass (1970), and this work is opening new vistas of understanding of the effect of oil. The work of these latter authors suggests that the consequences of pollutant hydrocarbons in marine ecosystems is as yet not understood.

Blumer's (1969, p. 10) studies on the fate of organic compounds in the marine food chain found that hydrocarbons, once they are incorporated into a particular marine organism, are stable, regardless of their structure and that they may pass through many members of the marine food chain without alteration and may actually be concentrated in tissue. This is a situation similar to the chlorinated hydrocarbon group of pesticides, which concentrate in the marine food chain to the point where toxic levels are reached.

The entrance of oil-derived hydrocarbons into marine food chains is evident. Smith (1968, p. 49) reported that the presence of oil and benzeneering compounds in the feces of limpets browsing on an oily deposit has been demonstrated chemically; similar observations have been made on top-shells, Monodonta, and limpets, Patella, living on oily rocks at Perranuthnoe. He reported, "...the proportion of oil in material ingested by these animals was estimated as about 20-30 percent in Patella and
Smith (1968, p. 65) believed it unlikely that any food value to the browser is derived from such feeding activity. However, such feeding activity does concentrate hydrocarbons in organisms that in turn are eaten by larger animals and the oil thus enters the food chain.

Large amounts of tar were found in the stomachs of three saury, *Scomberesox saurus*, from a sample of ten in the Mediterranean Sea near Gibraltar by Horn, et al. (1970, p. 246). Although these authors note that the saury is said to feed upon small crustaceans and perhaps upon small fish, they also note that "vegetable debris" was found in the stomach of one saury, which suggested the species is not a very discriminate feeder. They point out, however, that because this fish is fed upon by porpoises and larger predaceous fishes, a direct introduction into the ocean food web of material known to be toxic occurs. Mironov (1968, p. 336) notes the ability of some zooplankton organisms to accumulate hydrocarbons, assuring exposure at all trophic levels.

Hydrocarbons are not foreign to the marine environment; they are synthesized by most, if not all, living organisms. Unicellular algae can produce normal paraffin hydrocarbons from carbon dioxide, water and nutrients; paraffinic hydrocarbons are found in most living organisms of the sea (Clark, 1966; Clark and Blumer, 1967).

There are certain characteristic differences, however, between biologically produced hydrocarbons and pollution hydrocarbons, both in the distribution of various hydrocarbon classes and in the molecular size of the hydrocarbons. Crude oil and petroleum products are complex mixtures that contain molecules of different sizes in a fairly even
distribution, whereas living organisms utilize specific biosynthetic pathways that lead to specific hydrocarbon size groups (personal communication to D. R. Evans from R. C. Clark, Jr., 1971).

Hydrocarbons are fat soluble and thus have the potential to be retained and accumulated in organisms (Blumer, et al., 1970, p. 17).

Olefinic hydrocarbons are not generally found in crude oils, but are plentiful in gasolines and other refined products. The fate of olefins in the marine environment is poorly understood, but this class of compounds is quite reactive and will combine readily with hydrogen, oxygen, chlorine, sulfur and other elements to produce toxic substances. Once incorporated into organisms, olefins remain stable.

Shellfish, in addition to their significant contributions to the planktonic life of marine ecosystems, are of special recreational and commercial interest in their adult form. That oil pollution is damaging to shellfisheries is becoming well documented. Blumer, et al., 1970, p. 25) reports that the closure to taking of shellfish oysters, scallops, soft shell clams and quahags -- was maintained into the second year following the West Falmouth spill. They note that the presence or absence of an "oily smell" is no clue for presence of oil pollution in shellfish or fish.

A more pessimistic view is taken by Blumer (1969) who has stated: "...we are rather ignorant about long-term and low level effects of crude oil pollution. I fear that these may well be far more serious and long lasting than the more obvious short-term effects." Blumer (ibid.) then points out that hydrocarbons are taken up into the food chain, and through the process of 'biological magnification', can become concentrated in marine species used by man for food. He states, "One consequence
will be the incorporation into food of materials which produce an undesirable flavor. A far more serious effect is the potential accumulation in human food of long-term poisons derived from crude oil, for instance, of carcinogenic compounds."

8.1 Conclusion on Bioaccumulation

Bioaccumulation of any fraction of crude oils and petroleum refinery products present a potential hazard as follows: 1) commercially important marine species could become tainted and rejected as a food source, and 2) as an oil pollutant pathway in which oil undergoes biological-magnification and thus becomes an increased hazard to higher trophic levels.

1. Tainting of shellfish has been observed for #2 fuel oil and for crude oil. Shellfish areas were closed for over a year in the area of the West Falmouth spill. Oysters exposed to sublethal concentrations of crude oil maintained an oily smell for several months after exposure (Mississippi State University). Tainting potential of food sources would be related to the persistence of the material in the environment. Thus, persistence was involved in developing the relative rating of crude oil and petroleum for the profile. Crude oil and fuel oil were given a ++ rating for the above stated reasons. A rating of + was given to other petroleum refinery although no evidence was presented because they contain olefinic hydrocarbons which when incorporated into organism remain stable. (See Figure 3)

2. Biological magnification of oil in marine environment could be a problem; therefore, was given a + rating. Most of the evidence was for fuel oil and crude; therefore, a rating of ++ was assigned.
9.0 Carcinogenicity

The higher-boiling aromatics act as slower poisons than the lower boiling aromatic hydrocarbons, but they are equally severe in their effect. In addition, some are known to cause cancer. Benzpyrene, 1,2-benzanthracene and alkylbenzanthracenes have been isolated from crude oil and their carcinogenic effects on animals and man demonstrated (Blumer, 1970, p. 4).

Some doubt may remain as to the direct carcinogenicity of crude oil and crude oil residues in marine organisms according to Blumer (1969, p. 9), but evidence pointing toward this is accumulating (Blumer, 1970, p. 4). A literature search and evaluation conducted for the U.S. Coast Guard by Battelle Memorial Institute (1967, pp. 6-19) noted that shellfish, although alive, may be unfit for consumption because of the carcinogenic hydrocarbon 3,4-benzpyrene found in their bodies. Oysters that were heavily polluted and contaminated with ship fuel oil were also reported to contain 3,4-benzpyrene. The Battelle review also reported barnacles attached to creosoted poles located in marine waters contained the same carcinogenic hydrocarbon (3,4-benzpyrene), and it elicited sarcomas in mice when extracts from the barnacles were injected into the mice. The endemic occurrence of papillary tumors around the rectal opening of soft shell clams (Mya arenaria) was reported, but the author (Battelle Memorial Institute, 1967, pp. 6-19) did not feel these were due to oil pollution, even though the clams were taken from waters adjacent to areas highly polluted by ship fuel oil. Carcinogenic effects from chronic pollution may occur in the plankton as already demonstrated in benthic bryozoans (Powell, et al., 1970).
Sources and Biodegradation of Carcinogenic Hydrocarbons
C. E. ZoBell

Conference on Prevention and Control of Oil Spills 1971

3,4-Benzpyrene BaP

<table>
<thead>
<tr>
<th>Crude</th>
<th>mg/kg</th>
</tr>
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<tr>
<td>Persian Gulf</td>
<td>400</td>
</tr>
<tr>
<td>Venezuela</td>
<td>1600</td>
</tr>
<tr>
<td>Libya</td>
<td>1320</td>
</tr>
<tr>
<td>Motor oil</td>
<td>26 mg/kg</td>
</tr>
<tr>
<td>Waste oil</td>
<td>5800</td>
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</table>

9.1 Conclusion on Carcinogenicity

Crude oil and petroleum refinery products contain compounds that are known to cause cancer. The known carcinogenic compounds are accumulated by marine organisms. Based on this information, a rating of + was given to all oils. Higher concentration of the carcinogenic hydrocarbon 3,4-benzpyrene are found in petroleum refinery products than in crude oil.

10.0 Amenities

Visible oil pollution of the seashore and waterways is an increasing problem. The tourist industry is economically important to many coastal areas and impact from oil pollution may affect the economy of an area.

10.1 Conclusion on Amenities

An amenity rating was based on the persistence of oil in the marine environment as it may relate to the coating of beaches.
11.0 Human Health

Low-boiling aromatic hydrocarbons comprise the most toxic petroleum fractions. The low-boiling aromatics are acutely poisonous to man and marine organism alike. Benzene, toluene and phenols, such as found in crude oil, produce in man reactions similar to those of alcohol. The initial reaction is restlessness, then excitement, inebriation, drowsiness, depression and sleep. Death may follow from respiratory failure as the concentration rises (Goldacre, 1968). Chronic exposure to low concentrations of some aromatics, especially benzene, may cause bone marrow disease, chromosome aberration, and leukemia (Finkel, 1960). Low-boiling aromatics, even more water soluble than the saturates, can cause mortality of marine organisms by contact, even with dilute solutions (Blumber, 1970, p. 5). Bioaccumulation of carcinogenic hydrocarbons in seafood may be a potential health problem.

11.1 Conclusion on Human Health

The effects of petroleum refinery products and crude oil to human health are unknown.
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Wells, P. G., Influence of Venezuelan crude oil on lobster larvae: Mar. Pollution Bull. 3 (7), 105-1-6, July 1972.


Sanders, H. L. et al. As above, I Biology.

Unpublished data developed through an Interagency Agreement by the National Aeronautics and Space Administration, Mississippi Test Facility, for the U.S. Environmental Protection Agency, entitled "Environmental Effect of Oil and Hazardous Polluting Substances."
Fig. 1.-- EFFECT OF MIXING ON MENHADEN KILLS

FUEL OIL No. 2 IN WATER COLUMN (mg/liter)

BLENDER MIX

MAGNETIC MIX

STIR MIX

0 24 48 72 96

HOURS

Blender Mix
Survival Rate

Percent

0 50 100

24 Hours 96

Magnetic Mix
Survival Rate

Percent

0 50 100

24 Hours 96

Stir Mix
Survival Rate

Percent

0 50 100

24 Hours 96
Figure 2
TOLERANCE OF THE MULLET
To Various Refined Petroleum Products and Crude Oil

FUEL OIL No. 2
FUEL OIL No. 6
JET FUEL
LEADED GASOLINE
CRUDE OIL
## Figure 3

<table>
<thead>
<tr>
<th>Material</th>
<th>Acute Hazard</th>
<th>Chronic Hazard</th>
<th>Persistence</th>
<th>Degradation</th>
<th>Bioaccumulations</th>
<th>Carcinogenic</th>
<th>Amenities</th>
<th>Human Health</th>
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### Key:
- Number Ranking
  - 1 highest relative potential
  - 10 lowest relative potential
- ++ Evidence of adverse effects
- + Evidence of concern
- * No evidence
- Evidence of no detrimental effect
Fig. 4 COMMERCIAL FINFISH FISHERIES